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3D Printed Frequency Selective Surfaces for Microwave Absorbers

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by

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Abstract

A flat periodic FSS (frequency selective surface) is presented, which is fully fabricated by a 3D-printer and commercial 3D printing filaments which normally are used for printing metal like structures. The FSS absorber structure was developed and optimized for 10 GHz, fabricated with the 3D printer, measured afterwards and compared with the simulations. Further simulations were made with the new materials at higher frequencies and the results confirm that 3D printing technology works well and could be used to the best advantage for absorbers and other applications in the frequency range below 100 GHz.

Keywords: 3D-Printing, absorber, printed absorber, FSS.

Biography

Rainer Kronberger is head of the High Frequency Laboratory at TH Cologne University of Technology, Sciences and Arts. He graduated at Technical University Munich and did his PhD at the University of the Armed Forces, also in Munich. His main work was about small and integrated car antennas for communication services, diversity systems and array antennas for vehicles. In 1999 he joined Fuba Automotive / resp. Delphi Automotive, where he was responsible for advanced antenna engineering for automotive antennas. In 2002 he changed to Infineon Technologies in Munich, where he was head of the innovations group for the Wireless Business Unit of Infineon. Since 2004, he has been with TH Cologne. His main research is still on small communications antennas, on RFID systems for UHF and above and on flat absorbers for microwave applications. Prof. Kronberger is member of IEEE and VDE. He has made about 90 publications for conferences and journals and helds several patents.

Patrick Soboll studied communications engineering at the Cologne University of Applied Sciences (TH-Köln, Germany) where he received his B.Sc. and M.Sc. degrees in 2013 and 2015. Since 2014 he also works as research associate in the Radiofrequency Laboratory of TH Köln, focusing on antenna simulation and development. He has authored and co-authored six journal and conference papers. He was awarded first place in the IEEE IMS Student Design Competitions in the years 2014, 2015 and 2016 as well as in the IEEE WPTC Student Design Competition in 2016.

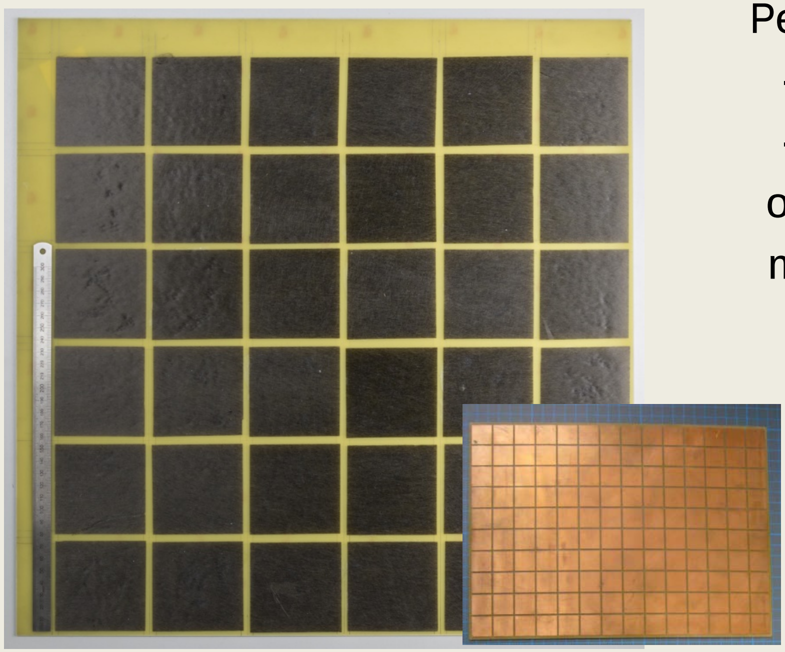
Outline

- Motivation and Idea
- Characterisation of the 3D printing materials
- Absorber design process
- Experiences
- Measurements
- Future Work / future applications

Motivation & Idea

Flat absorber design with well known FSS structures *

Main task: construction of material/surface to achieve absorption by impedance matching and losses



868 MHz 10 GHz

Periodic conductive structures

- i.e. isolated patches , loopes etc.
- or inverse holes in the conductive surface

on top of a dielectric layer
mostly grounded (PEC)

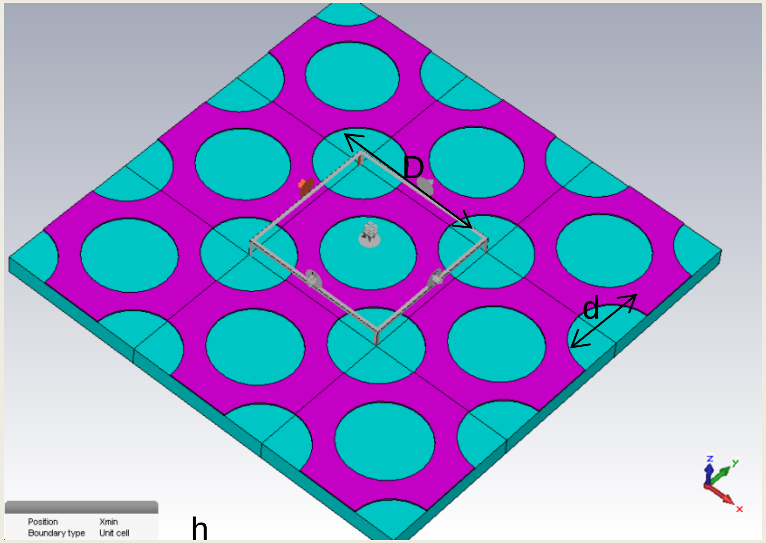
FSS provides good absorption

* Ben Munk, "Frequency Selective Surfaces: Theory and Design", Whiley, ISBN: 978-0-471-37047-5, May 2000.

Motivation & Idea

Typical FSS-Design process:

- choose structure / pattern
- define materials (type, size, etc.)
- start simulation with EM-software
- optimization, design, measurement



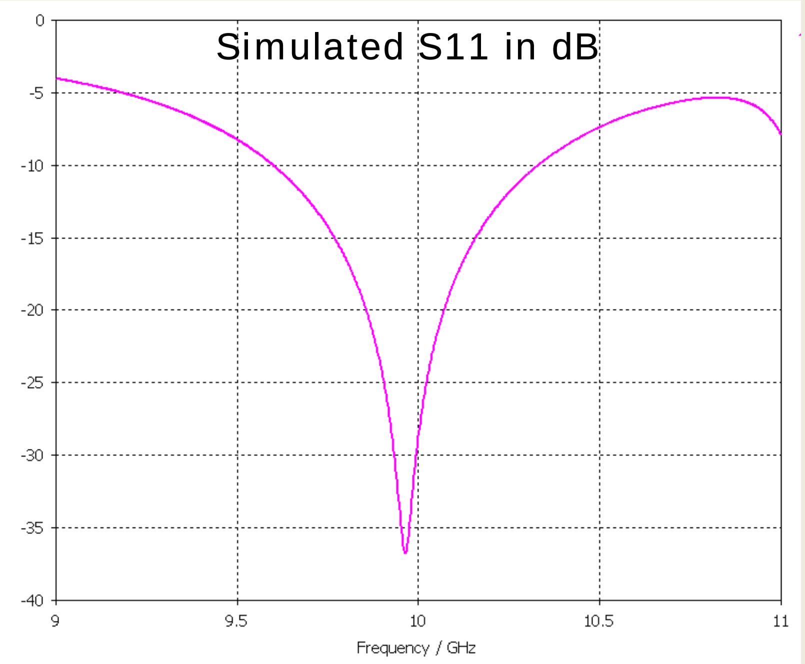
Diameter of holes d = 22 mm

distance between holes D = 36 mm

Layer conductivity σ = 60 S/m

dielectric layer (chloroprene foam)

h = 5 mm; ε_r = 1.135 tanδ = 0.015



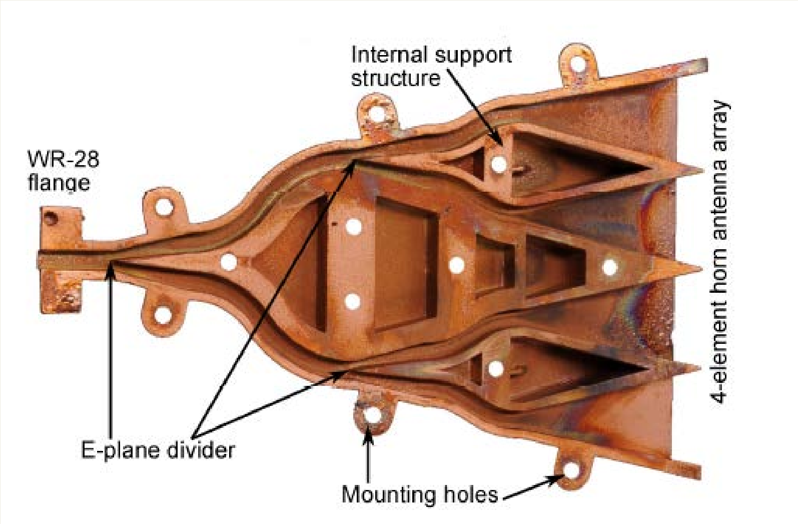
Material parameters are mandatory for the successfull design process!

3D-Printing for Microwave Applications

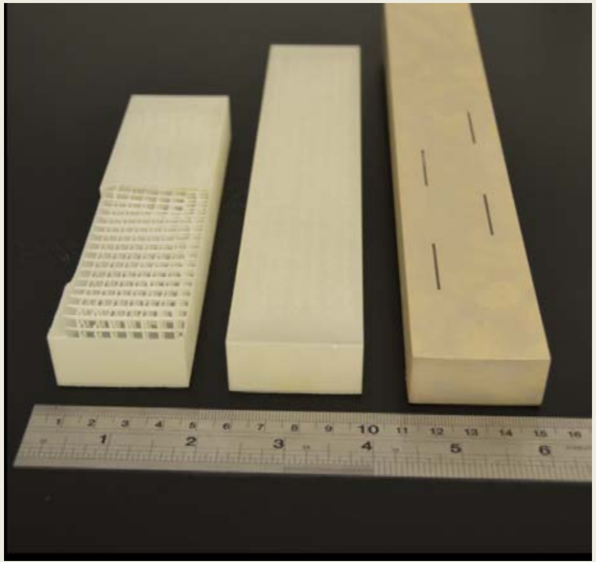
Some examples from recent publications

Straight Waveguide
Part No: VT100W/L100PPC
F: 8.2-12.5GHz
Vector Telecom Pty Ltd

3D printing for microwave: Materials characterization and application in the field of absorbers. Y. Arbaoui; V. Laur; A. Maalouf; P. Queffelec 2015 IEEE MTT-S IMS


Internal support structure
WR-28 flange
4-element horn antenna array
E-plane divider
Mounting holes

3D-printed low-cost, low-loss microwave components up to 40 GHz . Benjamin Rohrdantz; Christian Rave; Arne F. Jacob 2016 IEEE MTT-S IMS



Lightweight 3D printed microwave waveguides and waveguide slot antenna. G. McKerricher; A. Nafe; A. Shamim; 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting

3D-Printing

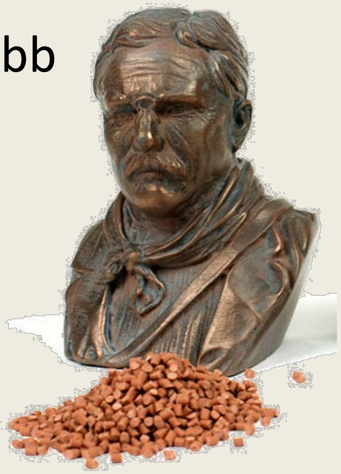
Ultimaker 2

- Our 3D-Printer: Ultimaker 2 (approx. 2.5 k€)

- Typical filament materials
  - PLA
  - PVC
  - ABS

MADE IN THE NETHERLANDS
colorFabb

- New printing filaments from colorFabb
  - **CopperFill**
  - **BrassFill**
  - **BronceFill**
  - CarbonFill

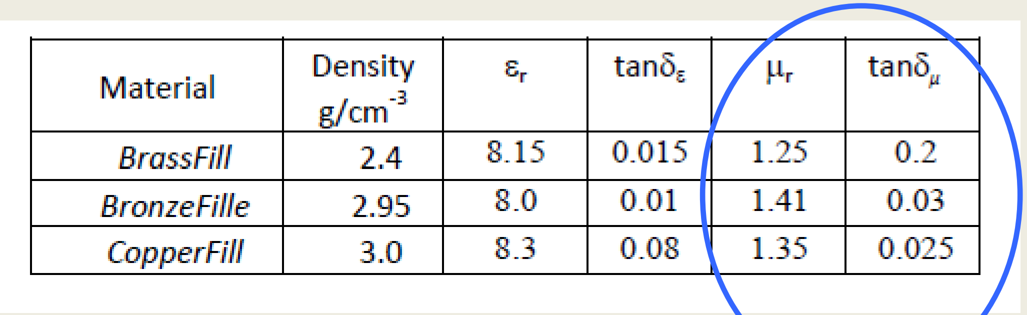


Can those materials be used for microwave applications?
Can we use our 3D-printer for creating microwave absorbers ?

Material Parameters of the Filaments

- Characterisation of the printing filaments

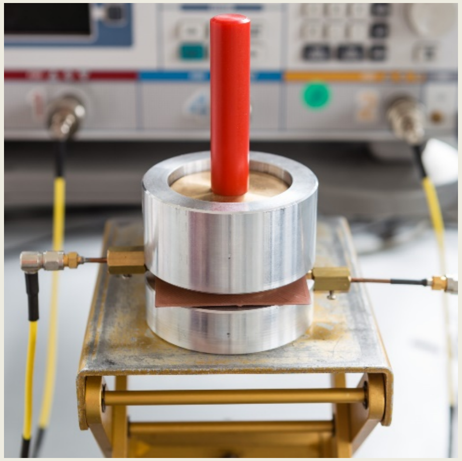
- Split cylinder measurements (Krupka)
- Waveguide measurements (Nicholson-Ross-Weir)

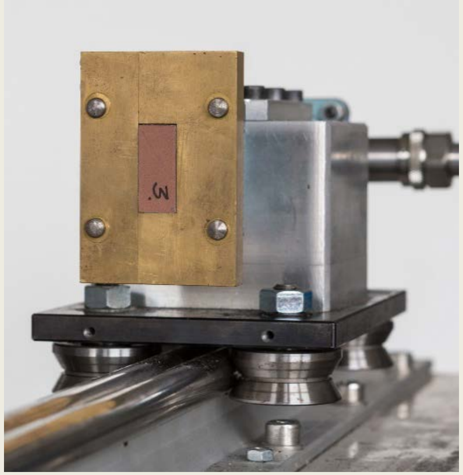


Material	Density g/cm^{-3}	ε_r	$\tan\delta_\varepsilon$	μ_r	$\tan\delta_\mu$
BrassFill	2.4	8.15	0.015	1.25	0.2
BronzeFille	2.95	8.0	0.01	1.41	0.03
CopperFill	3.0	8.3	0.08	1.35	0.025

Magnetic behavior!?

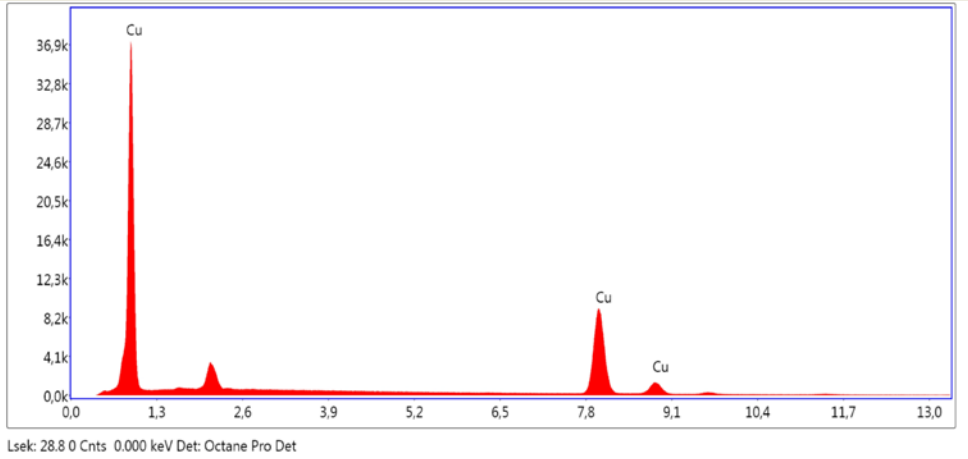
What are the reasons for magnetic behavior?
Is there carbonyl iron powder in the filaments?



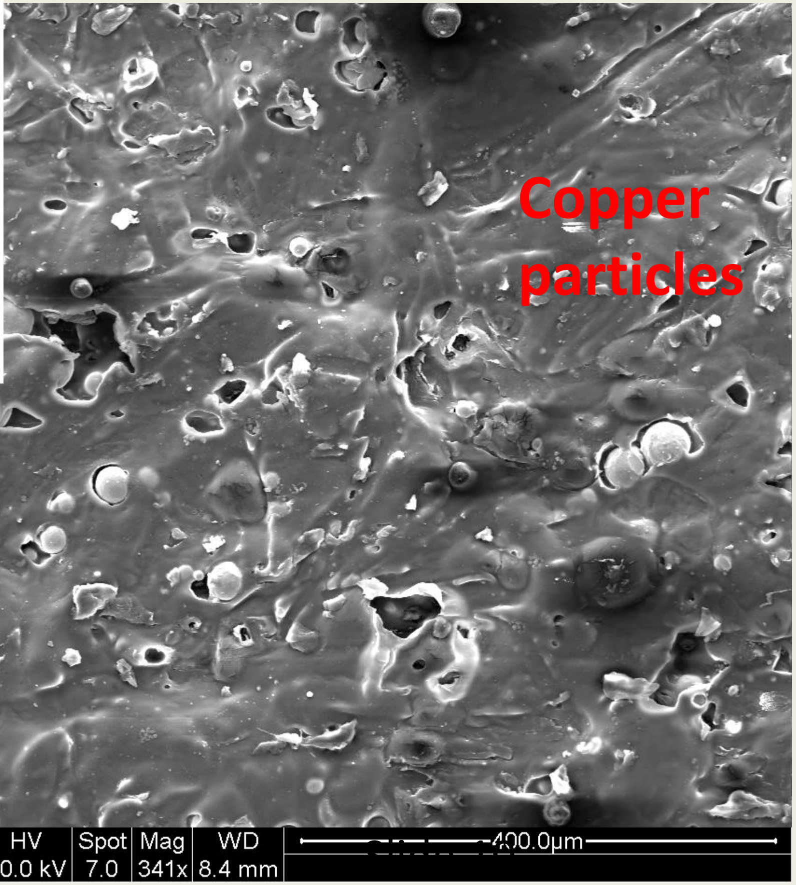


Material Parameters of the Filaments

- scanning electron microscope (SEM) measurements of the colorFabb filaments



Example: CopperFill


1/20/2016
11:18:15 AM
HV
20.0 kV
Spot
7.0
Mag
341x
WD
8.4 mm
400.0µm

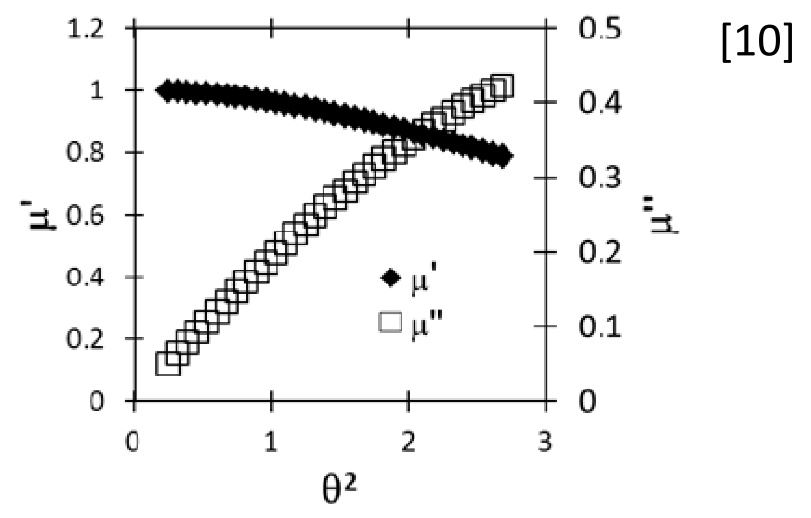
Copper particles

Only copper inside!

Magnetic behavior still unclear!

Material Parameters of the Filaments

- Artifical/effective permeability results from the ***Percolation Effect***
- Isolated conductive particles in dielectric medium/polymers form cluster.
- Those cluster cause eddy currents under influence of an EM-field
- This results an effective magnetic behavior (permeability)



[10]

Percolation effect depends on:

- particle density
- Particle size / type / material
- dielectric material

[10] A. Garner, G. Parker, L.Simone, Accounting for Conducting Inclusion Permeability in the Microwave Regime in a Modified Generalized Effective Medium Theory, IEEE Transactions on Dilectrics and Electrical Insulation, Vol 22, No 4, pages 2064 – 2072, Aug. 2015.

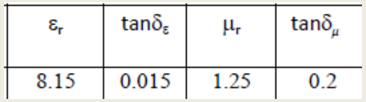
[11] T. Tsutaoka et. Al., Electromagnetic properties of metal granular composite materials for EMC applications, IEEE International Symposium on Electromagnetic Compatibility (EMC), 2012, pages 411 - 415, DOI: 10.1109/ISEMC.2012.6351812.

[12] I. Youngs, The shielding effectiveness of composite media – a parametric analysis supporting an engineering perspective, IEEE Transactions on Dilectrics and Electrical Insulation, Vol 14, No54, pages 1145 – 1153, October 2007.

Absorber Design

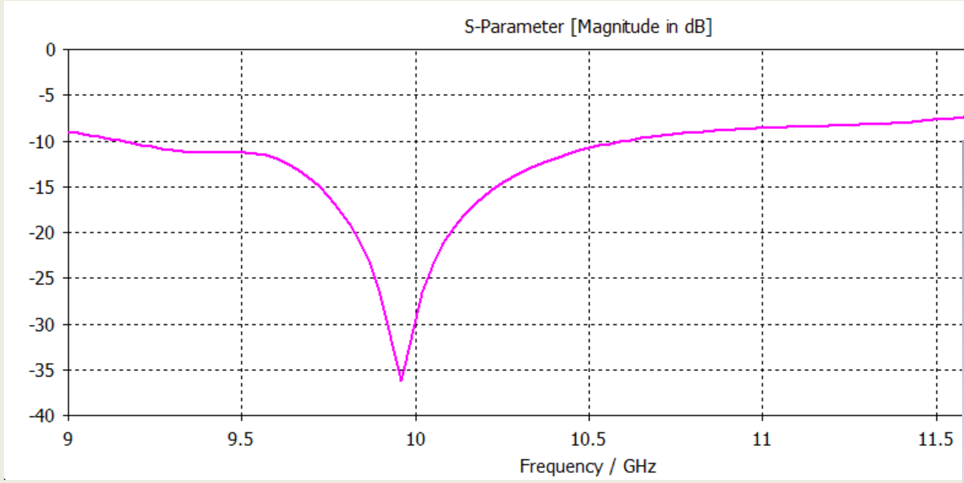
- First design: square patches on 3 mm air (foam) spacer on PEC

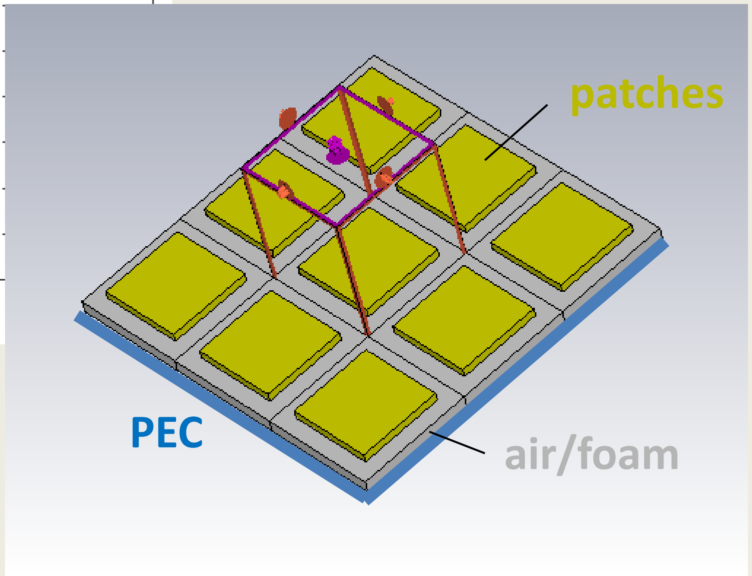
Patch material: brass fill



ε_r	$\tan\delta_\varepsilon$	μ_r	$\tan\delta_\mu$
8.15	0.015	1.25	0.2

Length: 20.6 mm
Distance: 28 mm
Height: 2 mm
on 3 mm Rohacell foam

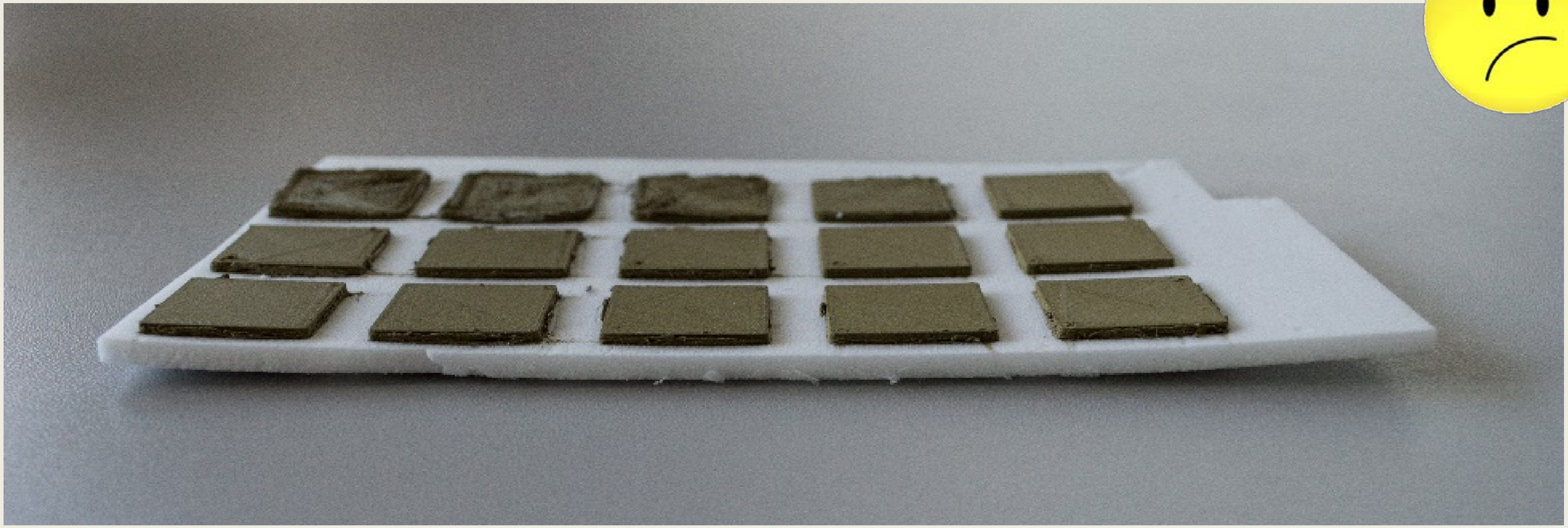




Simulation with CST

Absorber Design

First result: directly printed on 3mm Rohacell foam (printing time: > 3 hours!)



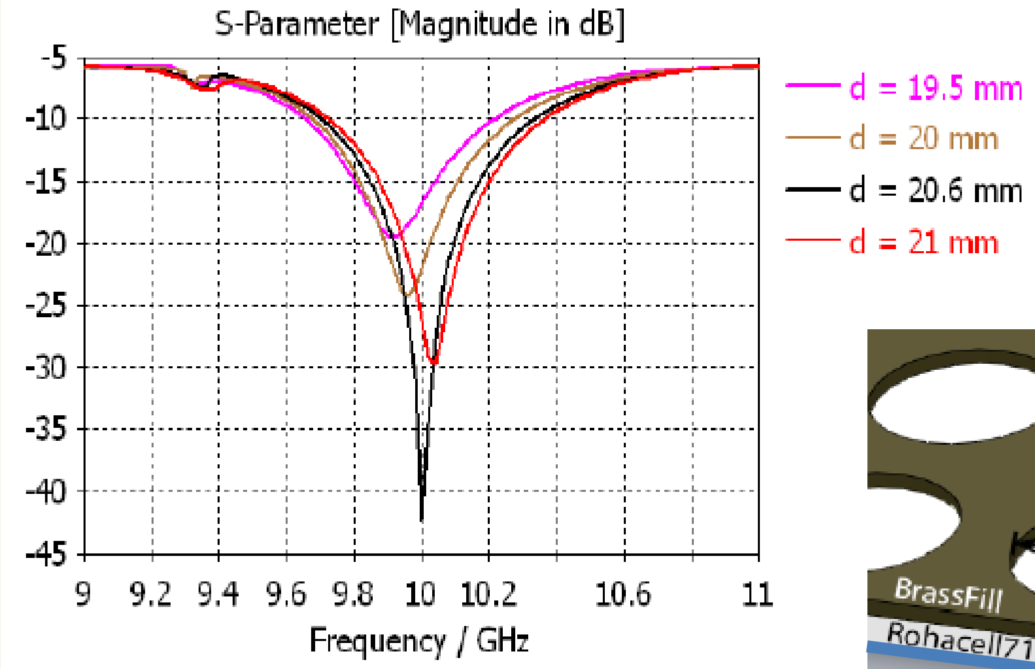
mechanical forces during the cooling process caused unexpected dishing!

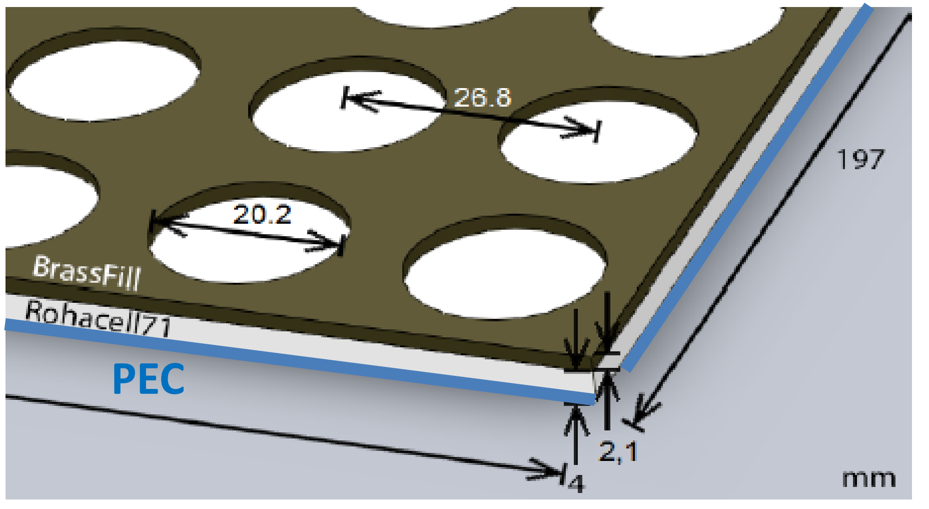
Absorber Design

- Second design: circular hole pattern in a flat sheet

Material: brass fill

Diameter: 20.2 mm
Distance: 26.8 mm
Height: 2.1 mm
on 4 mm Rohacell 71

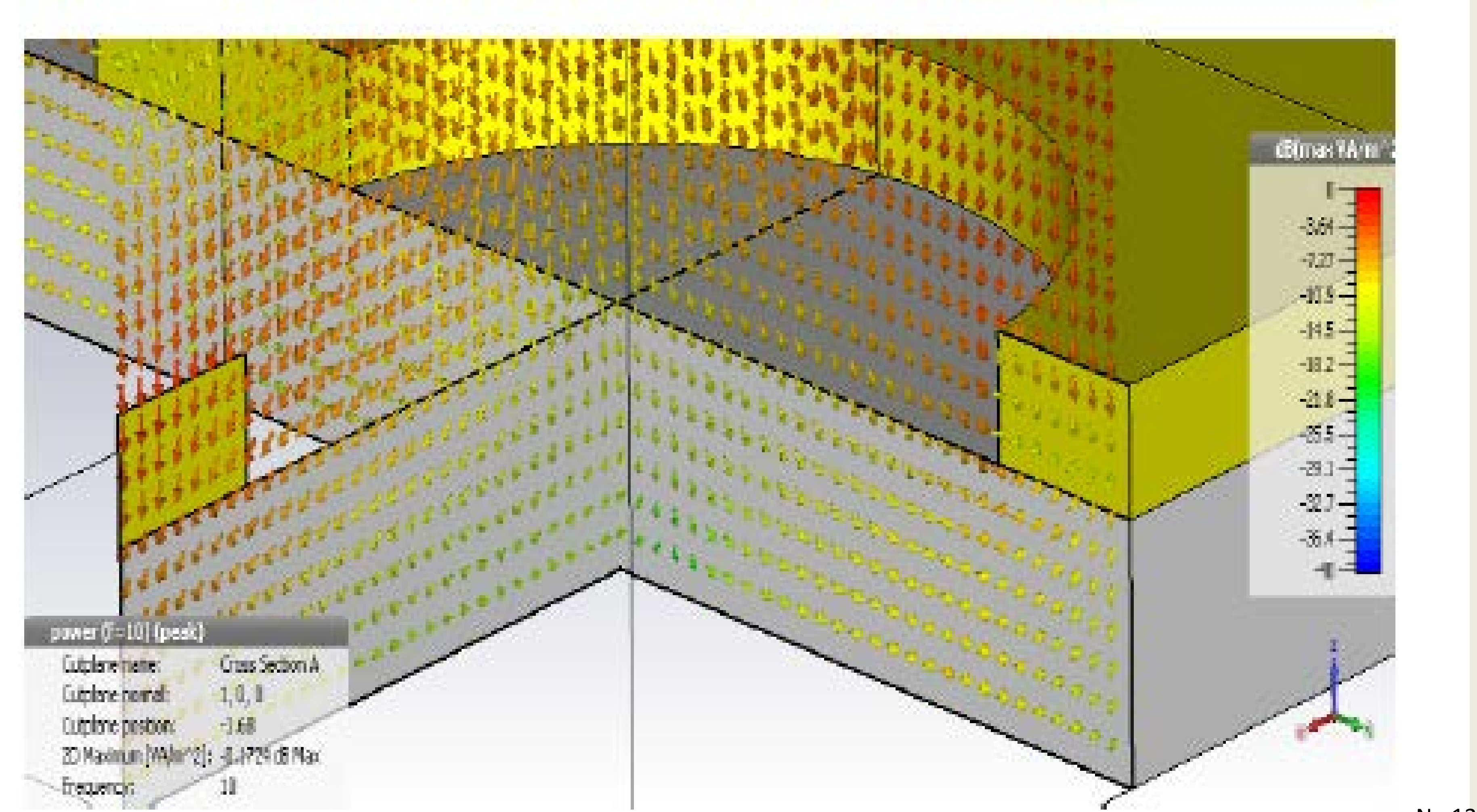



26.8
20.2
BrassFill
Rohacell71
PEC
197
2,1
4
mm

Idea: Print pattern as common block
and put it afterwards on Rohacell

Absorber Design

- Simulation of the power flow

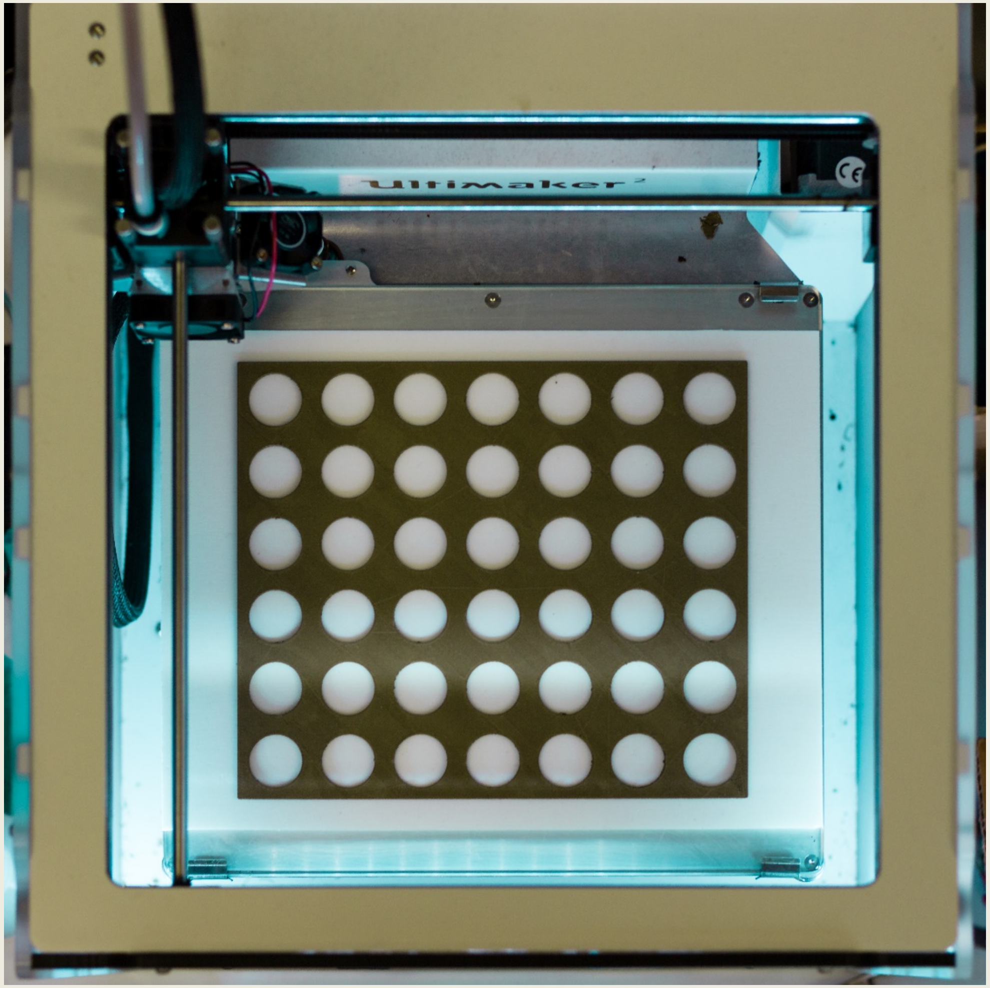

dB(max 1A/m^
0
-3.64
-7.27
-10.9
-14.5
-18.2
-21.8
-25.5
-29.1
-32.7
-36.4
-40

power (f=10) [peak]

Cutplane name:	Cross Section A
Cutplane normal:	1, 0, 0
Cutplane position:	-1.68
2D Maximum [W/m^2]:	-8.1729 dB Max
Frequency:	10

Absorber Design

- Second design: circular hole pattern in a flat sheet



Size: ca. 200 mm x 170 mm

Printing time: > 8h

Printing layer thickness: 0.1 mm

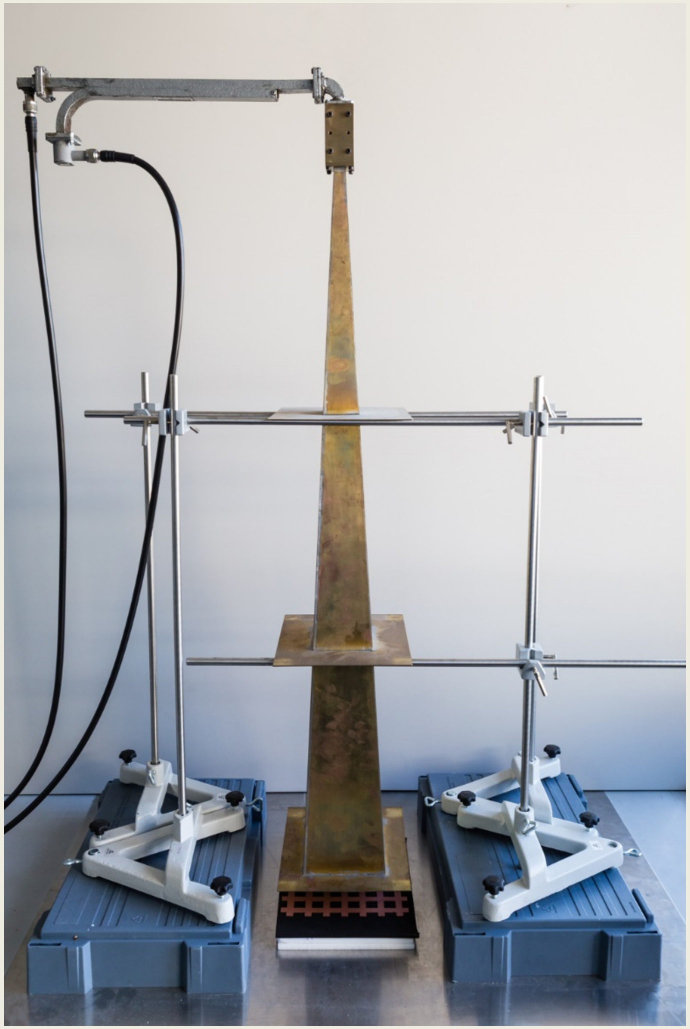
Desired height: 2 mm

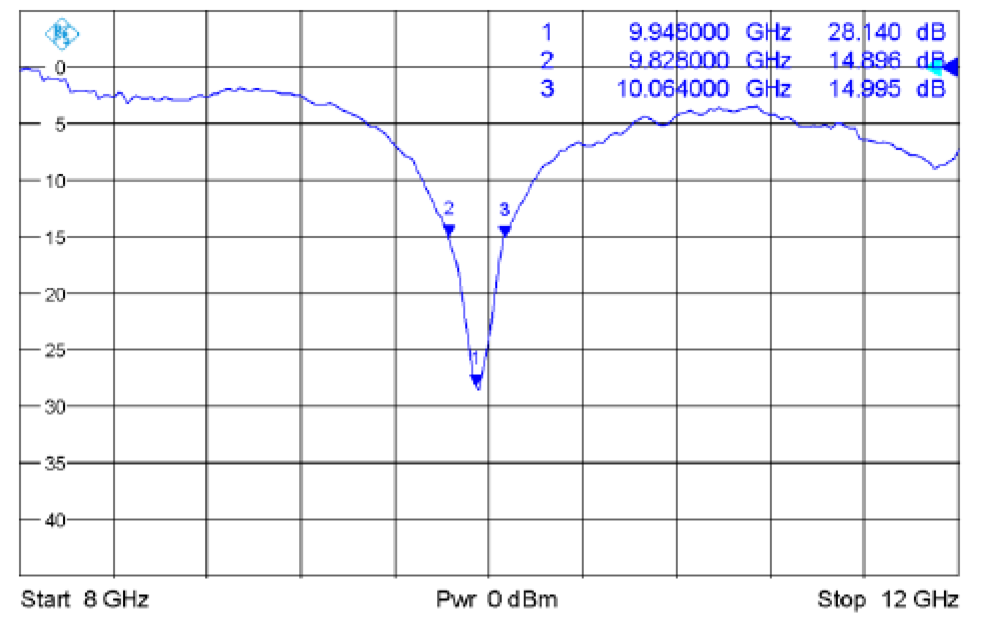
Measured height: 2.1 mm

Printing accuracy: < 0.1mm

Measurement results

- Measurements



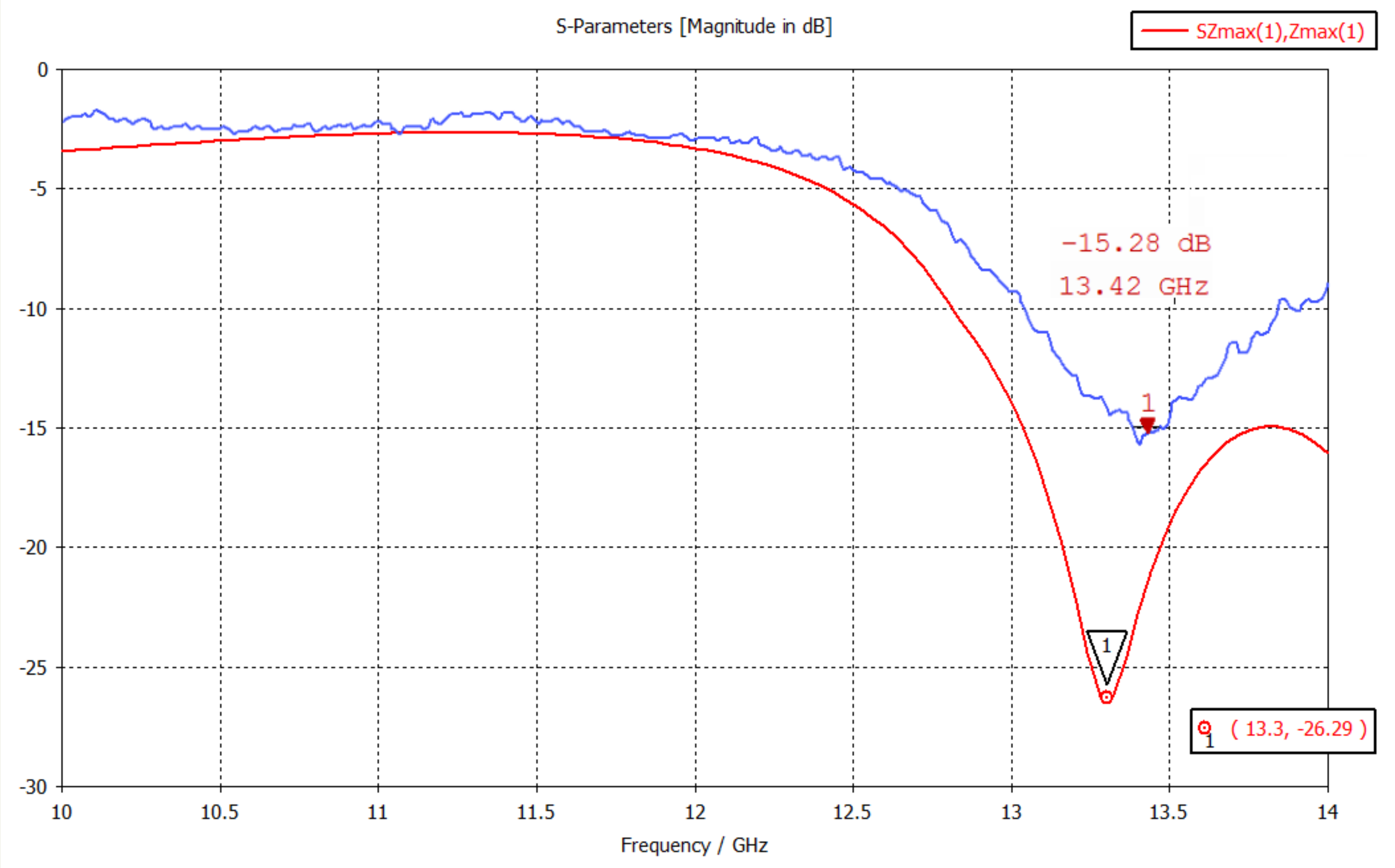


1	9.948000 GHz	28.140 dB
2	9.828000 GHz	14.896 dB
3	10.064000 GHz	14.995 dB

	measured	simulated
Center frequency	9.94 GHz	10 GHz
Bandwidth@15dB	282 MHz	320 MHz
Absorption (center)	28 dB	42 dB

Measurement in very good accordance to simulation !

- Verification: new frequency → geometrical changes



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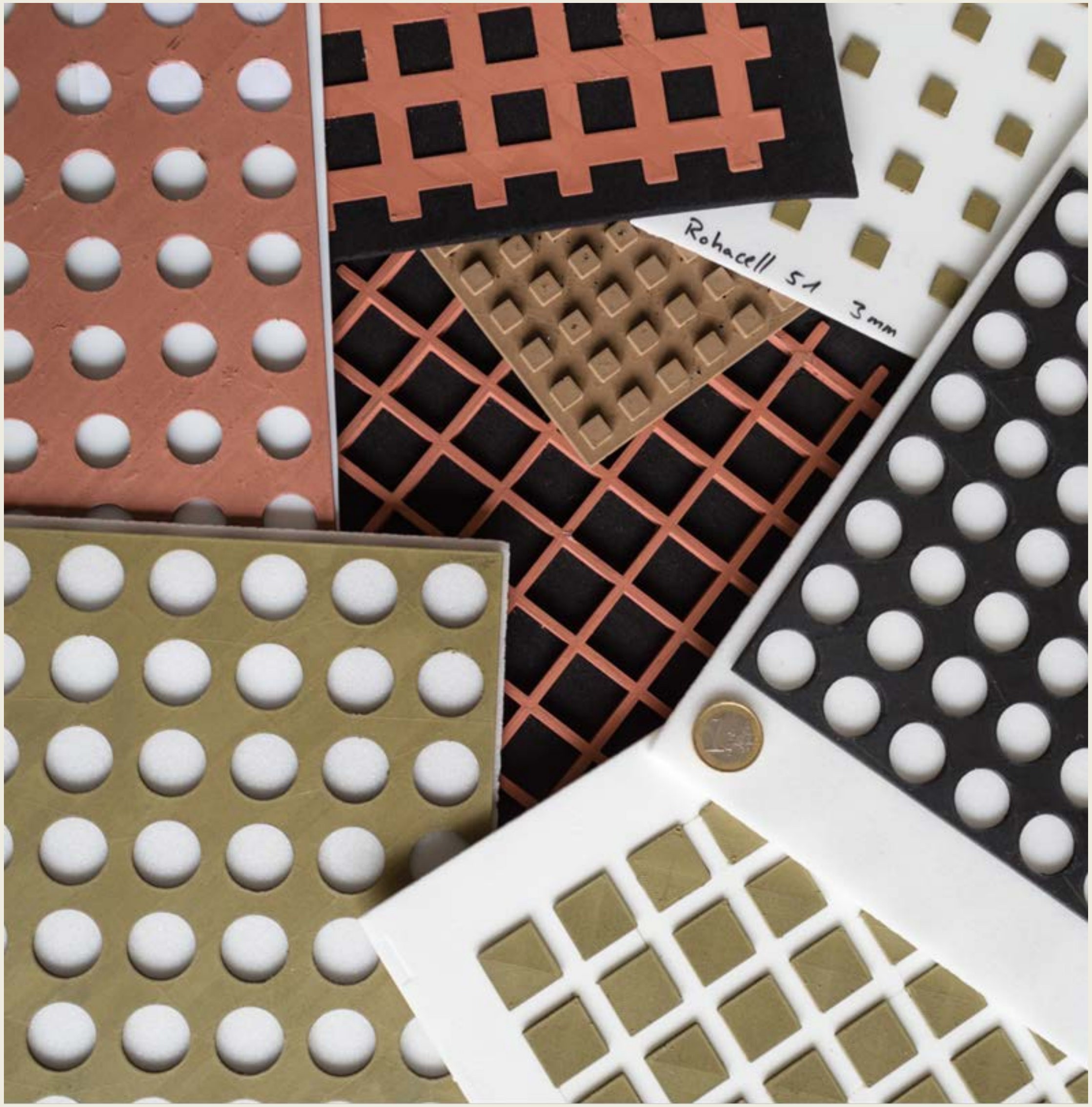
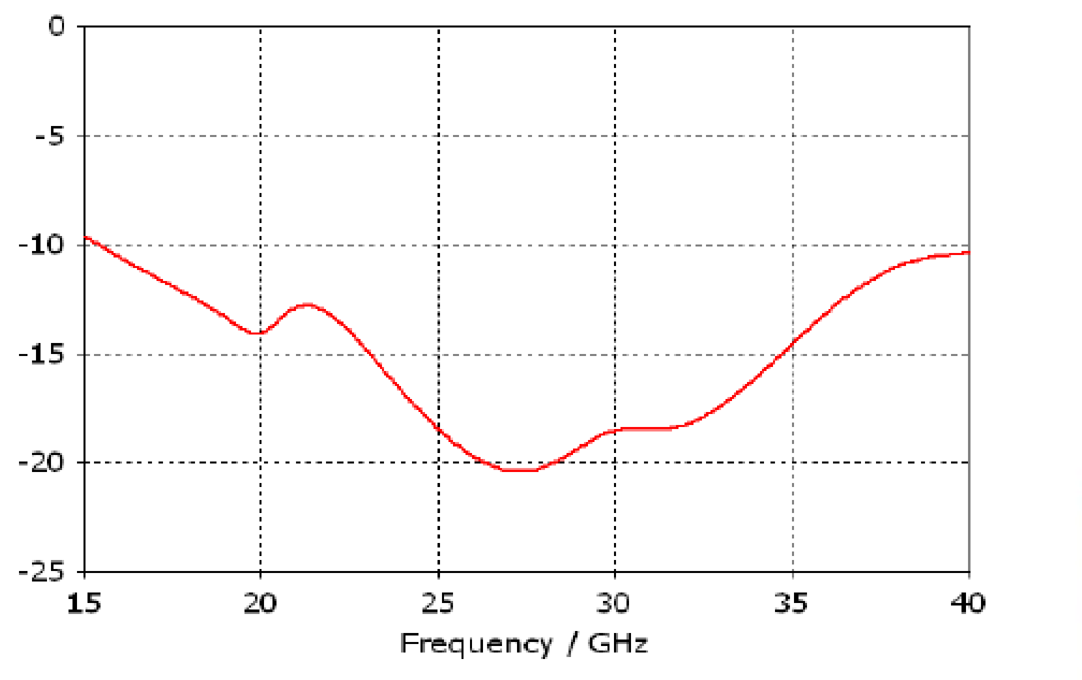
Some other printed absorbers


Rohacell 51
3 mm

Future Possibilities

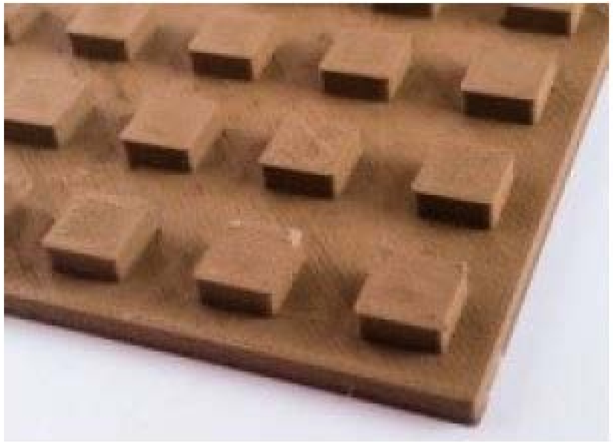
Simulation of a 3D FSS structure



*simulated with permittivity only!

3D-printing allows fast and easy realization of absorptive 3D structures !

3D printing of the complete structure



Cuboids 8.5 mm, h= 3.5 mm, on 3.3 mm ground layer

Conclusions

- 3D printing for a variety of microwave applications has been proven and tested!
- New 3D printing material with low conductivity is available!
- Difficult to determine the material parameters
- Material is well suited for FSS absorber design!
- FSS sheets /pattern can be realized directly with 3D printing!
- Simulation and measurement results fit very well!
- In future, 3D printing will allow more and other applications!
- Fast and easy realization of microwave devices!